•Pavement Management Guide • November 2001•

EXECUTIVE SUMMARY REPORT

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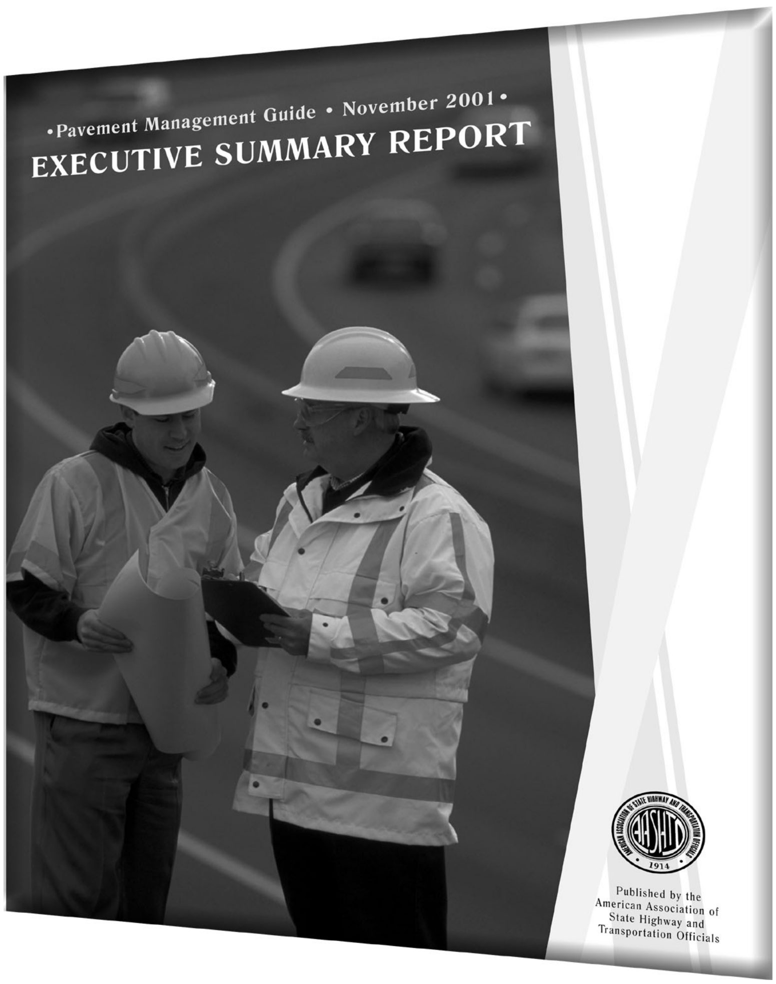

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Contents

ABSTRACT

This document is an Executive Summary to the Pavement Management Guide, which was published by AASHTO in 2001, and discusses technologies and processes pertaining to selection, collection, reporting, management, and analysis of data used in pavement management.

The objective of this executive summary is to distill the contents of the guide and provide an introduction to the concepts and principles of pavement management appropriate for senior management personnel and others who are not directly engaged in daily pavement management activities.

Executive Summary, Pavement Management Guide

INTRODUCTION

State, local, and federal agencies have spent billions of dollars constructing the current system of over 45,000 miles of interstate highways, over 111,000 miles of other National Highway System (NHS) roads, and over 3,700,000 miles of other roads and streets in the United States. In 1993 agencies spent over $87 billion on U.S. highways, roads, and streets (1). Approximately one-half that amount went directly into pavement construction, maintenance, and rehabilitation.

The amount of traffic, especially the number of miles traveled by heavy trucks, has continued to increase over the last 20 years as the economy has become more dependent on truck transportation (1). According to the "1995 American Travel Survey"(2), about 100 million households took approximately 685 million long trips, traveling about 827 billion miles. These trips are in addition to routine daily travel.

Our highway system is vital to our economy and our standard of living. However, more than half of the U.S. roads are in good, fair or poor condition. Most estimates show the funds currently being spent on roads are inadequate, indicating a need to spend the available funds more effectively. The purpose of pavement management systems is to help in making cost-effective decisions related to pavements.

The American Association of State Highway and Transportation Officials (AASHTO) has published the following definition for pavement management systems:

> "A pavement management system (PMS) is a set of tools or methods that assist decision-makers in finding optimum strategies for providing, evaluating, and maintaining pavements in a serviceable condition over a period of time."(3)

There is a key difference between pavement management and a PMS. Pavement management is a management approach used by personnel to make cost-effective decisions while a PMS is a set of tools used to assist managers in making those decisions.

A PMS can help an agency:

1. employ more cost-effective treatment strategies,
2. allocate funds to the pavement sections that will give the best performance for the funds allocated, and
3. improve the quality of the agency pavement network.

Engineers often hear questions such as: "Why are you always working on the roads? and "Do you ever finish working on those roads?" Those who work with pavements know that after a pavement is built, traffic and environmental loadings create unavoidable stress that will eventually reduce the condition of the roads to a point where they will not be useable without maintenance. They also know that early treatment will extend the life of some pavement.

The old colloquial saying of "pay me now or pay me later" applies to the life of pavements. Figure 1 shows a typical pavement deterioration rate with relative costs needed to maintain, or return, the pavement in a serviceable condition. The figure indicates that overall costs will be less if the pavement is treated early, even though the treatments must be applied often. Previous studies have shown that it "costs less to have good pavements than poor pavement (4)." However, this statement assumes that the pavement is structurally adequate, allowing the less expensive preventive treatments to be effective, that the costs being considered are long-term costs, and that the agency provides a sensible level of service to the using public over some reasonable analysis period.

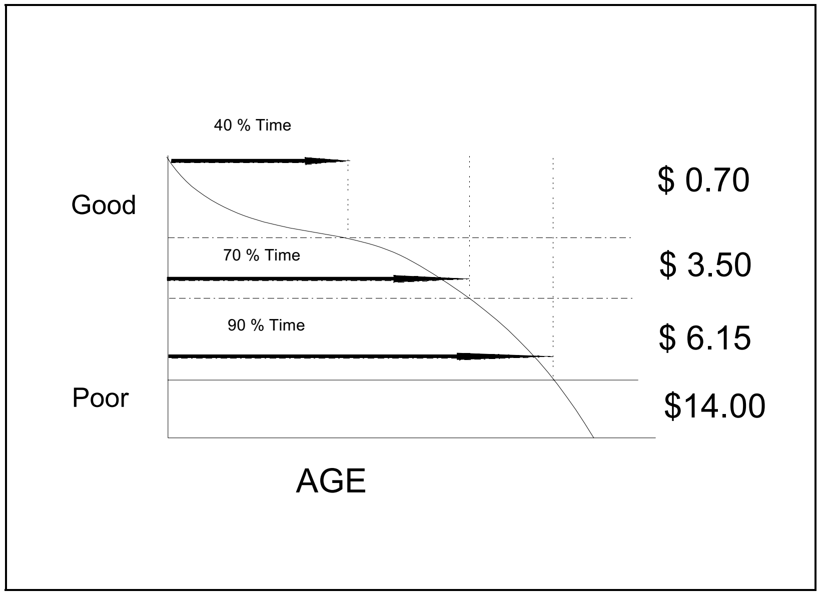

Figure 1. Effect of treatment timing on repair costs.

A road will not last for an extended period of time without application of some type of maintenance, rehabilitation, or reconstruction. Pavement management practices provide a rational approach to assist in finding a cost-effective combination of pavement sections and treatments to provide the level of service selected by the managing agency. A PMS provides a means to organize the massive amount of data that develops with a road and street network. It facilitates data storage, retrieval, and the complex calculations needed to quickly and efficiently identify cost-effective alternatives. They also provide the ability to develop information needed to support policy changes and justify maintenance and rehabilitation programs.

In the broadest sense, pavement management covers all phases of pavement planning, programming, analysis, design, construction, and research (5). As implemented in most agencies, pavement management systems primarily address maintenance, rehabilitation, reconstruction, and sometimes, new design. The systems generally look only at the maintenance and rehabilitation needs of the existing pavement system. Increased capacity needs are normally addressed in congestion management or other planning activities. Maintenance addressed in pavement management is primarily programmed or planned preventive maintenance treatments. While pavement management systems normally do not try to predict where a pothole will appear or the frequency of routine maintenance activities such as pothole filling, information from pavement management systems indicating deferred rehabilitation work does provide information to maintenance personnel on which segments that are likely to have significant maintenance needs. Maintenance management systems normally address routine, emergency, and other unprogrammed maintenance work requirements; however, the maintenance management systems should interface with the pavement management system so each system is aware of the work completed and programmed by the other.

PAVEMENT MANAGEMENT LEVELS

Pavement management is described, developed, and used in at least two levels: network and project (5). These two levels differ in both management application and data collected. However, the cost of data collection has normally forced a distinct separation between the two levels (6).

Several differences exist between network-level and project-level management processes (5,7). Although the differences vary among agencies depending on the size, organization, and other factors in the agencies, some or all of the following differences are generally found:

1. goals or purposes of the decisions;
2. groups or levels within the organization making the decisions;
3. number of groups, or individuals, who must develop and review the recommendations prior to submittal to the decision authority;
4. number of management segments considered in the analysis; and
5. detail of the data and information needed to support the decisions.

The first four are of interest because they identify the decision support needed at each level, while data are needed to provide the information used to support those decisions.

Network-Level Purposes

The purposes and goals of the network-level management process are normally related to the budget process and include (6):

1. identifying pavement maintenance, reconstruction, and rehabilitation needs;
2. determining funds needed to address these needs;
3. selecting feasible funding options and strategies to be tested;
4. determining the impact of these funding options on the health of the pavement system as well as the overall welfare of the using public;
5. developing a recommended funding option and funding strategy; and
6. selecting sections to be recommended for funding for the recommended funding option or strategy.

Project-Level Purposes

At the project level, the purpose is to provide the most cost-effective, feasible, and original design, maintenance, rehabilitation, or reconstruction strategy possible for a selected section of pavement within available funds and other constraints (5). Achieving this goal generally includes:

1. an assessment of the need for construction or cause of deterioration leading to the need for maintenance, reconstruction, or rehabilitation;
2. identification of feasible design, maintenance, rehabilitation, and reconstruction strategies;
3. analysis of the cost-effectiveness of the feasible alternatives or treatments;
4. definition of imposed constraints; and
5. selection of the most cost-effective strategy within imposed constraints.

Other Levels

Although many agencies use these two basic levels, some agencies use additional levels to support the decision-making processes. In several states the more expensive decisions, such as which new highway will be built, are centralized, while less expensive decisions, such as which road to overlay, are decentralized. When states use decentralized approaches, the primary support needed by the central management authority involves determining how much funding to allocate to each region or district. The region or district needs support in project selection.

Some agencies, particularly those with decentralized decision authority, include a third management level between network- and project-level analysis, which has been called the project-selection level. Haas and others identify this project-selection level as a part of the network-level analysis with the remainder of the network-level analysis being considered program-level analysis (5). The purpose of the project-selection level is to complete the process of selecting the segments that will be programmed for work with limited funding for the current funding cycle. This process includes preliminary engineering to identify feasible treatments, improving the cost estimate (which may include several work items that are not pavement related), and finalizing the list of sections to be treated in the current funding cycle. The project selection level requires more data than normally collected at network level but considerably less data than needed for full project-level design and analysis.

Although the network-level pavement management elements provide information for senior management at the legislative and administrative levels, senior management often wants to have the pavement information integrated with information from other management systems. In some agencies, this practice has been called an administrative management system. Recently, agencies have adopted asset management approaches or infrastructure management systems to assist with this strategic-level management. These systems will be discussed later in this chapter.

Differences Between Network, Project-Selection, and Project-Level Management

In many agencies, different groups within the agency are responsible for network, project-selection, and project-level management activities and decisions. Those who make the final network-level decisions are in high positions within their organizations and often have some level of authority in allocating the specific funds being managed. In decentralized decision making, the senior district personnel approve a list of final projects and allocation of funds to each for the current funding period. At project level, decisions about which segment will be funded generally have already been made, and the engineering or maintenance staff, who must keep final costs for the treatment within the previously established budget, complete the treatment selection and final design.

In network-level management activities, agencies can include all of the pavement segments under their jurisdiction; however, many agencies manage subsets because of funding requirements. The quantity of pavement considered in project-level analysis is normally a single management section, which also often corresponds to an original construction section. However, in the analysis some management sections may be combined into a single project for contracting purposes, and other sections may be subdivided into more than one segment so that different treatments can be applied to individual portions of an original management or construction section.

Each purpose, decision level, and review level needs different amounts of information and detail in data. In general, as the purpose becomes more broad, less detail is needed and more summarized information is used (6). Information presented to funding authorities must be general in nature and include summarized trends. Those making decisions about what treatment is most appropriate for an individual segment must have data to complete at least the preliminary design of feasible alternatives. They should also consider the need for future maintenance and rehabilitation activities.

DESCRIPTION OF NETWORK-LEVEL ELEMENTS

The following paragraphs discuss each of the major elements needed in a decision support system. Specific tools, such as database managers are not included in this discussion but are vital parts of any computerized decision support system. The basic elements of a network-level PMS include (6):

1. an inventory;
2. a condition assessment;
3. determination of needs;
4. prioritization of projects needing maintenance and rehabilitation;
5. a method to determine the impact of funding decisions; and
6. a feedback process.

In this discussion, the identification of candidate projects for funding is included in the network-level analysis. This programming element has been called project level by some agencies, but it is a portion of the network-level process (5) and will be included in this document, and in the discussion of network-level analysis. Later, a short section titled Project Selection discusses an intermediate phase of adjusting that list.

Overall, this system is composed of two major subsystems. The information management system collects, stores, and manages the data and any derived information that is stored. The decision support system is the collection of algorithms that analyze the data and provide recommendations to managers (8). However, both of these are required to assist with effective management of pavement systems, and in most discussions they are seldom separated. In the following discussion, a PMS will include both the information management and decision support components unless explicitly expressed otherwise.

Inventory

The network-level inventory, or database of basic information, includes information on the pavements the agency is responsible for managing.

The inventory includes information that defines the management sections and information about the location, limits, size, connectivity to other sections, number of traffic lanes, route designations, and functional classification for each management section. Some basic information about the pavement such as the layer materials, material properties, and dates of construction or application, is normally included in the inventory. This type of data is normally entered into the database once and is only changed when some significant change occurs in the data.

Data should never be collected because “it would be nice to have the data” or because “it might be useful someday.” Each data item collected requires time, effort, and money to collect, store, retrieve, and use later. Many agencies have found that it is more difficult to keep data current than it is to collect the data initially. Inaccurate or outdated data will reduce the credibility of any decision support based on that data.

Data should be collected only when that data element is important to the agency in making pavement maintenance and rehabilitation decisions at the level it is to be used and when it can be kept current (6). Different types, amounts, and accuracy levels can be used for network-and project-level analysis. Information not vital to the decisions at the network level should be deferred until it is needed at the project-selection or project-design level. The items included are selected to provide enough information to support effective management without burdening the agency with collecting an excessive amount of data.

Every effort should be made to collect data only once and make them available to all who will need them. Information about work on the pavement that is collected as a part of the construction and maintenance process should be recorded and stored in a format that will allow all potential users to effectively use that. If the data are kept only for a limited time period, critical data should be transferred to the pavement management database. However, the accuracy of this data needs to be well defined so that users will know which data are based on plans versus which is based on field investigations.

Condition Assessment

Pavement condition assessment begins with collecting data to determine the type, amount, and severity of surface distress, structural integrity, ride quality, and skid resistance of the pavement. Pavement condition data are necessary to determine maintenance and rehabilitation needs, project future condition, and identify the impacts of treatments. They are also used to identify feasible maintenance and rehabilitation strategies, prioritize work, and help optimize maintenance and rehabilitation fund expenditures.

Pavement condition is normally measured using one or more of the following factors (5,7):

1. **Surface Distress** - damage to the pavement surface. Distress surveys are performed to determine the type, severity, and quantity of surface observable distress.
2. **Structural Capacity** - the maximum load and number of repetitions a pavement is predicted to carry. Structural analysis is normally conducted to determine the current pavement load-carrying capacity which can be compared to the capacity needed to accommodate projected traffic.
3. **Roughness (ride quality)** - a measure of pavement surface distortion or an estimate of the ability of the pavement to provide a comfortable ride to the users.
4. **Surface Friction or Skid Resistance** - the ability of the pavement surface to provide sufficient friction to avoid skid-related safety problems, especially in wet weather.

The first two measures are generally considered measures of the engineering properties of the pavement while the last two are generally considered measures of the functional performance of the pavement. Other measures that may be used include the noise and water spray created by traffic.

These pavement condition measures can be used to determine the overall pavement condition and to help identify the most cost-effective maintenance or rehabilitation treatment. The pavement condition measures discussed above vary in their degree of importance in terms of pavement performance and maintenance and rehabilitation needs. Any treatment recommended to correct the structural load-carrying capacity of the pavement can address all other deficiencies that might be present, including roughness. Also, any treatment selected to correct pavement roughness can also be used to improve the surface skid resistance and correct any surface distress.

Several methods can be used to collect each of the condition measures (9,10). In general, procedures that require the least effort and cost the least are also the least accurate; those that are most accurate and provide the most detail are also the most expensive and time consuming. In general, most agencies use less accurate methods for network-level analysis and more detailed measures for project-level analysis.

Data can be collected and stored for data collection sections that do not have the same limits as management sections, or data can be collected for each management section. As more high-speed data collection techniques are used, more agencies collect and store data by data collection sections which are later analyzed in relation to the management sections.

The condition information collected can be prepared for use in several different ways (7,9). Some agencies use individual measures, including individual distress types, severities, and quantities, at network level. Other agencies combine distress information into single or multiple distress indexes such as cracking and pavement condition indexes. Other agencies combine several measures together into composite indexes, such as the present serviceability index (PSI) and road condition index (RCI) (5). Combining data into indexes provides single numbers that can be used to compare the condition of one section of pavement to another. However, this comparison is based on the concepts incorporated into the particular index used. Some indexes are primarily oriented to how the traveling public views the pavement (e.g., PSI), while others are oriented primarily toward what engineers think should be done to the pavement (e.g., PCI [pavement condition index]). Those who use indexes must understand the basis of the indexes, and they should be used only to represent the conditions upon which they are based.

Specific PMS software programs often require the use of a particular set of measures. Changing those measures may require that the decision support algorithms in the software also be changed.

Determination of Needs

Once the pavement network has been defined, basic information is known, and the condition data have been collected, most agencies then want to know what work is needed and the resources needed to complete that work. This process should identify the work needed over some defined analysis period to provide the level of service the agency wants to provide to their highway users without respect to available funds.

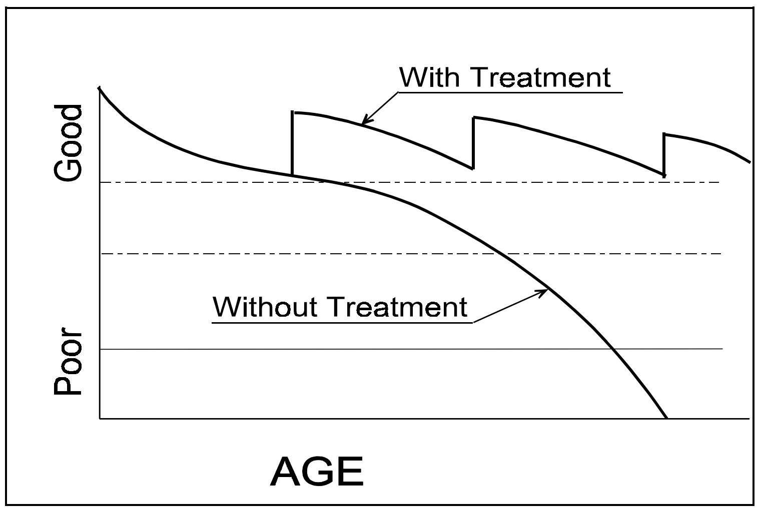

Figure 2. Projected condition without and with treatment

In general, identifying work needed requires that the condition of individual management sections without maintenance or rehabilitation, in terms of individual distresses, PCI, PSI, or some combination index as illustrated in Figure 2 (6) be projected to a common time frame and into the future. The projected condition of all sections in the network can then be used to determine the overall condition of the network at any time with or without treatment. The projected condition without treatment gives a base condition of pavement sections being analyzed, or the network as a whole, if no funds are spent.

A common method used to identify sections that need work is to compare the condition of each management section during each year over the analysis period to established decision criteria (trigger values) normally based on condition, surface type, functional classification, and traffic loadings (6). Figure 3 shows a condition index scale (0 to 100 where zero is low) with four different network-level treatment categories, preventive maintenance, light rehabilitation, moderate rehabilitation, and heavy rehabilitation (or reconstruction). The dividing lines between preventive maintenance and light rehabilitation, between light rehabilitation and moderate rehabilitation, and between moderate rehabilitation/reconstruction would be the trigger values. When the condition of a pavement is projected to cross from one level to another, a specific treatment is identified, or triggered. Agencies that use several condition indicators generally establish a set of trigger values for each different condition indicator, such as rutting, cracking, roughness, and surface friction. When one of the indicators for a segment of pavement reaches a trigger value, that segment is scheduled for the appropriate level of treatment. Different trigger values can be established for each functional classification, traffic grouping, and pavement type the agency uses in the management process.

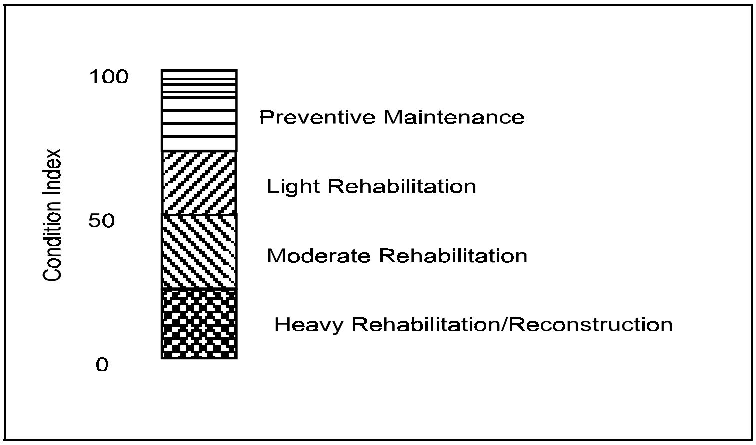

Figure 3. Trigger value example

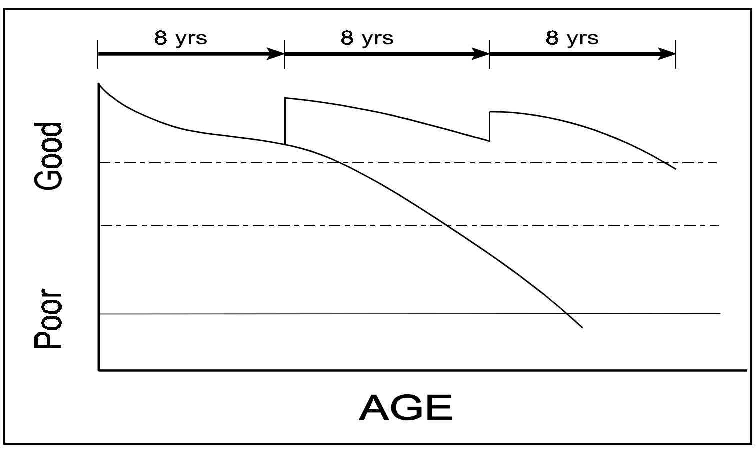

Figure 4. Projected performance with projected preventative maintenance

In this approach there generally is no trigger value for preventive maintenance. Instead, a cyclic time sequence application of treatments can be used until the segment of pavement reaches the first trigger value; then it would be scheduled for the appropriate treatment category. Figure 4 shows a projected performance for an asphalt surface pavement with a seal coat projected on an eight-year cycle.

When the pavement sections are identified for treatment, a network-level treatment category unit cost for pavements of that type and condition is used to determine the funds needed for that section at that time period. As sections are identified for treatment, the condition of each is increased in that year based on the expected effect of the treatment, and future work identified through the analysis period is based on that changed condition. The treatments and fund needs are summed for each year to determine annual work and budget needs over the analysis period. The condition of each management section and the overall network condition with all needed maintenance and rehabilitation applied projected over that analysis period gives a second base condition if all funds needed were applied. However, the amount of these fund needs depends on the level of service the agency selects to provide to the using public.

The purpose of the network-level budget planning treatment is to estimate total costs needed, but it is calculated by assigning a cost to each section of pavement which has reached a selected threshold value. These treatments should generally be considered cost categories rather than actual treatments; the actual treatment will be selected during the project selection or project-level analysis. ***The purpose of the network-level system is trying to identify candidate sections and the amount of money needed to achieve some department-defined goals***. Some sections will require more money than estimated, while others will require less; the funds needed by each section should not be designated until further analysis is completed.

This decision support algorithm requires models that project the condition of pavements without treatment, the impact of treatments on the condition, and the condition of pavements with treatments. It must be able to identify the sections needing work in order to meet agency goals. The algorithm must be able to match appropriate treatment levels to each section needing work in each analysis year, and it must be able to estimate the costs of applying those treatments over that analysis period. In many cases, multiple treatments will be required for individual sections during the analysis period.

The approaches used in this process must reflect the agency's methodology and values. They must be able to support the decisions that would be considered by the agency. These requirements will affect the data needed for the analysis; more complex analysis and more accurate projections generally require more detailed and more expensive data collection and storage.

Prioritizing Candidate Sections

Once an agency identifies the sections of pavement needing work and determines the funds needed to provide the desired level of service, those sections must be prioritized and funding allocated (7). In most cases, the available funds are inadequate. Even when adequate funds are available, they often must be allocated over a number of years to match the work with the available resources. The goal of prioritization is to provide the greatest benefit to the using public for the funds expended. This goal is often translated into providing the best possible pavement network condition for the funds expended; however, the pavements on highways with the greatest traffic are usually kept in better condition than those with lower traffic levels.

A large number of prioritization approaches are used in pavement management. A simple ranking procedure can be used; however, that type of procedure is limited in the number of factors available (7). Simple ranking procedures often rank those in the worst condition as the highest priority without regard to the return on the funds expended. This procedure may be adjusted for usage, which gives those in worst condition the highest priority, weighted for traffic levels.

The cost of maintenance and rehabilitation treatments changes with condition, as illustrated in Figure 1. Generally pavements in very poor condition require substantial funding to return them to the desired condition for any reasonable time period. To illustrate a need for some consideration of cost-effectiveness, the costs shown in Figure 1 indicate that 20 sections of pavement can be treated with preventive maintenance for the cost of a single section in the worst condition. The cost of two worst first cycles in Figure 1 would be $28 per square yard, while the cost of four chip seals and one overlay for the same time period would be $6.50 per square yard. Yet, over 50 percent of the time the pavement in the worst first cycle would be in less than good condition, while the section in the preventive maintenance cycle would be in good condition for the entire period.

Cost-effectiveness of treatments also varies by pavement type, traffic level, and the like. Ranking based on worst first is generally one of the least cost-effective methods, but it is also the simplest. Ranking approaches based on condition of the pavement over time, treatment costs over time, and importance of the road or street in terms that can be easily understood, supported, and explained to the elected officials can be used to give better estimates of the segments to select.

There are a number of "optimization tools" available which can determine the "optional allocation of funds" (11,12). These include linear programming, integer programming, Markov decision analysis, and dynamic programming. In general, each of these identifies the "best group" or "optimum combination" of management sections to select for treatment, the treatment to apply, and the year to apply the treatment over the analysis period. This selection is usually based on maximizing some function defined as a benefit for some set level of funds or minimizing the funds required to provide some minimum desired benefit. Various constraints can be applied over the analysis period.

Several factors have inhibited the use of true optimization tools in PMS. Some agency personnel oppose their use because the techniques are complex and provide answers that they cannot readily understand or explain to their supervisors, funding authorities, and others. When an agency has a large backlog of needs, the solution space associated with optimization can change significantly. For example when small changes are made in available funds, the recommended selections from some optimization approaches often change dramatically. Managers that must present a list of sections to be treated have a difficult time convincing senior managers that the list of segments and treatments for any one year should change dramatically when small changes in available funds are made.

One of the largest impediments to using an optimization tool, or any benefit-cost analysis, is the difficulty in quantifying the benefits derived from pavement construction, maintenance, rehabilitation, or reconstruction. Recent studies have identified the problems with the available tools (13). User costs such as travel time costs, accident costs, environmental costs, and vehicle operating costs have all been used to some extent. There are problems with each of these costs that are described in Reference 13. However, all of these costs do not show the full economic impact of having better transportation facilities. If used without other information, agencies will often allocate all funds to the highest used facilities allowing the low-usage facilities to deteriorate to the point of becoming impassable. This other benefit, which some economists have called "access value," determines the benefit of having increased access to a parcel of land. Even with all of these deficiencies, many agencies consider user costs in some portion of project selection and funding analysis. Very few agencies, however, use it exclusively.

Because of the problems related to optimization procedures and defining benefits, some agencies use heuristics, such as marginal cost-effectiveness, in a multi-year prioritization as an alternative to true optimization. These "near optimal" solutions are often easier to explain and the list of recommended sections and treatments for each year tend to be more stable than some of those from true optimization approaches. A number of surrogates have been used instead of true benefit-costs including area under performance curves, area above performance curves, and the like.

The particular approach used for prioritization or optimization will affect the type of data that are needed to support the analysis. More complex analysis and more accurate results generally require more detailed, more accurate, and more costly data to support the analysis.

Determine the Impact of Funding Decisions

It generally requires considerable justification to get funds for long-term solutions that either do not show immediate impacts or that cost more than short-term solutions. One of the best ways to justify funding requests is to show the impact of alternate funding levels and strategies on the health of the network, the backlog of needs, future fund needs, and user costs.

The health of the pavement network can be shown by projecting the average condition of the pavement network over some reasonable analysis period with various levels of funding and various funding strategies (e.g, higher and lower percentages of funds directed at preventive maintenance [1, 3]). However, some agency staff allocating funds often may not understand what change in condition is significant, thinking only in financial terms. It is often best to describe the current quality of service and to discuss how the funding strategies under consideration will increase or decrease the condition, with an emphasis on the percentage of each type of road in one of several levels. Showing the percentage change of highways in poor condition with the current and alternative funding levels may be more appropriate. Those allocating funds may also have to show current fund needs, backlog of fund needs, and amount spent on stop-gap maintenance activities and how they will change over time for different funding alternatives.

The change in number of pavements that need rehabilitation or maintenance and have been deferred because of funding limitations may also help in discussions with funding authorities. The remaining life of the existing network and changes in remaining life with different funding strategies are also helpful to some agencies. Changes in user costs may be useful for those officials who are interested in the financial impacts on their constituents.

Feedback System

Many of the pavement management systems currently being used were implemented with projection techniques, assignment processes, and costs based on limited information. A system must be reliable and robust before it can become fully adopted and used. The feedback process provides information on how well past estimates have matched observed values and provides information to improve future estimates (2). The projections are compared to actual observed information, and the projection techniques are modified to make them more reliable. These feedback and updating processes may not be a part of the software, but rather a manual process. Agency staff responsible for operating the PMS are also responsible for updating projection algorithms, assignment processes, and costs on a recurring basis.

DESCRIPTION OF PROJECT-LEVEL ELEMENTS

Most engineers have more experience in project-level activities than network-level management. After the network level, management elements identify candidate projects for programmed maintenance, rehabilitation, and reconstruction. The engineering staff generally prepares the final list of segments for work along with plans, specifications, and cost estimates during project-level analysis.

Project-level pavement management is the process of analysis and design to determine the layer material types, properties, and thicknesses needed for the pavement structure that will give the best service to the public for the least cost (7). Although computer programs may be used in designing layer thicknesses of specific materials and in economic analysis, much of the process must be completed outside a computerized pavement management software program. The complete project-level analysis can require considerable in situ testing and materials sampling and testing.

PROJECT-SELECTION LEVEL

Some agencies include a third management level between the network- and project-level analysis, which has been called the project-selection level. The purpose of the project-selection level is to complete the process of prioritizing or optimizing the segments that will be programmed for work with constrained funding. This process includes assigning the level of treatment, establishing the timing of the treatment for pavement segments over the analysis period, and determining more accurate cost estimates. It generally requires more data than would be collected at network level but less data than needed for full project-level design and analysis.

After completing the normal network-level analysis, those segments that are obviously not candidates for maintenance, rehabilitation, or reconstruction in the analysis period can be removed from further review. Those segments for which the appropriate levels of treatment needed are obvious can have the level of treatment established. The remainder of the segments are then identified for additional data collection and analysis. However, the data collected would still be less than that needed for project-level design. Additional factors that affect the cost estimates beyond what is available in the PMS are then determined.

Some of the agencies completing the project-selection level of analysis currently do not use the computer software to assist in the process; other agencies use software that allows treatments to be fixed in the process to support this type of analysis. Others allow a time sequence assignment technique. However, the agencies are generally collecting a minimum amount of additional data and using that to adjust the treatment level, resulting cost, and timing of treatments. This analysis is used to help identify those conditions that can create large variations from the average costs normally used at the network level. Project-selection analysis is particularly helpful when the pavement analysis drives the decisions about which sections should be considered primary candidates for work, but where other costs, such as traffic control, safety improvements, and drainage can become quite large compared to the actual pavement rehabilitation costs.

THE MOVE TO INFRASTRUCTURE MANAGEMENT

As the costs to operate and maintain the highway transportation system in the U.S.A. have increased and the funds available have been reduced, there is an increased need to support fund requests with relevant justification. Infrastructure management systems were developed to help address additional types of facilities with individual management systems and to start the move towards integrating the management of all physical facilities managed by the agency.

The more numerous and complex the infrastructure systems become, the more there is a need for coordination of data management. Data collection, storage, and retrieval are the most costly parts of maintaining infrastructure management systems. When management systems for several different highway facilities are developed separately, some data will be duplicated and similar data will be collected differently. Combining some of the data collection activities will likely save money.

Coordination can occur at several levels, but it should include some or all of the following:

1. location referencing;
2. data definitions;
3. data collection processes;
4. conflict analysis;
5. needs analysis; and
6. fund allocation.

THE MOVE TO ASSET MANAGEMENT

While public agencies were using individual facility management systems and were moving toward infrastructure management systems, private industry was using asset management concepts to support decisions related to their facilities.

Recently, the AASHTO and the Federal Highway Administration sponsored workshops and investigations into applying asset management concepts in transportation agencies (14,15). Although there is no universally accepted definition of asset management, the first conference used the following definition, which was repeated in the second workshop (14,15):

> "Asset management is a systematic process of maintaining, upgrading, and operating physical assets cost-effectively."

This definition was further expanded with the following description in the first conference (14):

> "It combines engineering principles with sound business practices and economic theory, and it provides tools to facilitate a more organized, logical approach to decision-making. Thus, asset management provides a framework for handling both short- and long-range planning."

In the second workshop, the assets managed by transportation agencies were defined as (15):

> "physical infrastructure such as pavements, bridges, and airports, as well as human resources (personnel and knowledge), equipment and materials, and other items of value such as financial capabilities, right-of-way, data, computer systems, methods, technologies, and partners."

This list broadens the scope of asset management from the physical assets identified in the first definition to include several non-physical items. Since asset management is new to transportation agencies, we can expect further changes in both the definition and scope.

While there are similarities and differences between network-level and project-level pavement management, there are similarities and differences among pavement, infrastructure, and asset management. Pavement management focuses on pavements; infrastructure management focuses on physical facilities; and asset management can include all elements managed by the agency, including many non-physical assets (financial capabilities, methods, and technologies). However, the basic management concepts are the same in all three: to provide the best return for the funds spent. Network-level pavement management, infrastructure management, and asset management have the same general goals for the facilities and assets managed, and they require the same basic components that were earlier described for network-level pavement management.

The focus of the decision support from these three systems seems to be different—although, this is not well defined. The pavement management decision support is generally directed toward those who make decisions about the pavements; the infrastructure management systems are directed toward those who must allocate funds among the different types of infrastructure facilities; and asset management systems are directed toward the policy-making level. All of these systems are a cross between engineering and planning, but of the three, pavement management seems to be most closely related to engineering, while asset management seems to be closer to planning.

One of the implementation problems encountered in pavement and infrastructure management has been developing information in a style and format that can be easily communicated to senior management and funding authorities. In his presentation to the second asset management workshop, Lemer suggested that an infrastructure balance sheet and infrastructure income statement be developed as a part of an integrated infrastructure asset management system (16). This type of focus allows those funding authorities who are more familiar with private industry to view the allocation of funds and resulting benefits in a form that many of them are familiar with.

As asset management matures, it will attempt to better integrate the management of physical assets and possibly non-physical assets. Pavement management is one of the tools that most transportation agencies have in place, and it should be one of the first that is integrated into an overall management approach. The lessons learned from implementing and using PMS should be helpful in asset management, and the lessons learned in developing tools to better communicate with policy makers in transportation agencies should help guide future developments in pavement management.

ORGANIZATIONAL IMPACTS

There are several methods that can be used for each element in a network-level PMS, and there are many different data collection procedures that can be used. There are a number of conditions and situations in any organization that affect the PMS elements and procedures that are most appropriate for the agency. Agency size, organizational structure, past management and decision-making practices, stability, planning horizons, resources, and fixed investments will all have an impact. Selecting the appropriate procedures and software can have a major impact on the difficulty and success of the implementation process, whether it is implementation of a new PMS or implementation of a revised component in an existing PMS.

BENEFITS OF PAVEMENT MANAGEMENT

There are many benefits of having a structured PMS implemented in a highway agency. Some of the identified benefits include:

1. more efficient use of available resources (17,18), and
2. ability to justify and secure more funding for pavement maintenance and rehabilitation (19,20,21).

Some other benefits that agencies derive from a structure pavement management process include:

1. more accurate and accessible information on street system;
2. quantified condition of network;
3. ability to track the performance of selected treatments;
4. supportable needs analysis;
5. ability to show impact of funding decisions;
6. selection of more effective maintenance and rehabilitation strategies;
7. improved communication between different groups working with pavements in the organization and with the public;
8. ability to answer pavement questions from management, elected officials, and the public;
9. better coordination of work with utility agencies;
10. improved credibility when dealing with management, elected officials, and the public; and
11. a sense of satisfaction knowing that the agency is doing the best possible job with the available funds.

Until recently, it has not been possible to document the monetary benefits of PMS. A recent study conducted in Arizona documented a conservative benefit-cost ratio to the Arizona DOT of thirty dollars savings in pavement expenditures for every one dollar spent on PMS development, implementation, and operation (22). If user costs were included, the savings would be considerably higher, about $250 saved for every dollar spent on PMS. Savings by other states will vary, but the level of return for the amount of investment would still be expected to be very high. This does not mean that the agency will have extra money left over, rather it provides funds that can be used for other needs.

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